TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 531

WELDING RUSTPROOF STEELS

By W. Hoffmann

From Autogene Metallbearbeitung
December 15, 1927 (Vol. 20)

Washington
September, 1929

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

TECHNICAL MEMORANDUM NO. 531.

WELDING RUSTPROOF STEELS.*

By W. Hoffmann.

Since the discovery of rustproof steels and the recognition of their advantages, their field of application has steadily increased, especially where undesired chemical attacks on metals and metal alloys take place. Their use is increasing with the improvements in the process of welding them.

The most used rustproof steels are high-percentage chrome and chrome-nickel steels. A special advantage of chrome steel, aside from its resistivity to corrosion, is its suitability for structural purposes, because of its superior mechanical properties and its strength even at high temperatures.

The following experimental results will perhaps increase the knowledge of the process of welding rustproof steels. The experiments were made with two chrome-steel sheets and with two chrome-steel-nickel sheets having the composition shown in Table I.

*"Ueber das Schweissen von rostsicheren Stählen," a paper read September 4, 1927, at the annual meeting of the German Acetylene Society in Düsseldorf. From Autogene Metallbearbeitung, December 15, 1927 (Vol. 20), pp. 337-343.

TABLE I.

	Designation	C	Si	Mn	Cr	Ni
1	Chrome steel	0.45	0.31	0.30	13.8	-
2	Chrome steel	0.17	0.65	0.54	14.61	-
3	Chrome-nickel steel	0.35	0.62	0.70	12.81	20.90
4	Chrome-nickel steel	0.17	0.58	0.48	20.95	6.79

The physical properties of the chrome-steel and chrome-nickel-steel sheets are given in Table II.

TABLE II.

Designation	Treatment	Yield point kg/mm²	Breaking strength kg/mm²	Elongation %	Shrinkage %	Hardness 5/500
1	750-820°, $\frac{1}{2}$ hr.	47.4	54.9	13.18	60.6	214
2	750-820°, $\frac{1}{2}$ "	47.7	58.4	15.2	52.1	170
3	Untreated	-	83.8	17.9	53.7	179
3	1100°, $\frac{1}{2}$ hr., oil	-	77.1	31.9	54.8	277
4	1100°, $\frac{1}{2}$ ", "	-	83.6	34.2	42.6	238

Welds were made with acetylene and oxygen and also with the electric arc. Wires or rods of the same chemical properties as the materials listed in Table 1 provided the additional welding material. It is well known that, in both gas and arc welding, the molten welding material, in passing from the welding rod to the welding place, has the opportunity to absorb oxygen and nitrogen either from the burning gases or from the air. The easily oxidizable constituents of the welding material (namely, carbon, silicon, and manganese) are thus reduced, as shown in Figure 1. The great loss of these elements in gas welding lessens the strength of the material. In the arc process the absorption of oxygen and nitrogen is small, while the strength is increased by the absorption of nitrogen. In order to determine the loss in welding chrome and chrome-nickel steels, one to four analyses were made of the materials melted in the gas flame, as well as in the electric arc. The results are given in Table III.

TABLE III.

Designation	C	Si	Mn	Cr	Ni
Arc 1	0.38	0.29	0.40	13.54	-
Gas flame 1	0.18	0.14	0.11	10.48	-
Arc 2	0.15	0.58	0.44	14.75	-
Gas flame 2	0.05	0.32	0.21	13.28	-
Arc 3	0.30	0.40	0.38	12.10	18.25
Gas flame 3	0.18	0.22	0.29	11.63	15.10
Arc 4	0.11	0.28	0.32	19.20	7.10
Gas flame 4	0.08	0.31	0.16	15.37	5.27

From the loss thus determined, it is seen that, through the alloy of Cr and Ni, it differs from the percentage reduction of C and Mn shown in Figure 1. In gas welding, care must be exercised to keep the known ratios of the diameter of the welding rod, gas pressure and flame adjustment the same as in welding ordinary steel. Any excess of oxygen must always be avoided, since otherwise there would be too great a loss of Ni and especially of Cr. Any excess of acetylene must be avoided, since this would result in a harmful absorption of carbon by the metal. In the gas-welding experiments, it was found that the weld was not so deep as with ordinary steel, so that even thin sheets had to be welded on both sides.

Attempts to weld the chrome and chrome-nickel rods by the electric arc showed a great loss in the added components, especially in chromium. After the chrome and chrome-nickel rods were provided with a protecting covering during the welding in the electric arc, this loss was reduced. By adding the reduced constituents in the form of powder to the protecting material, the original excellence was approximately attained. A better way to avoid the reduction is to add correspondingly larger proportions of the alloys to the welding rods.

In welding clean chrome and chrome-nickel rods in the arc, the melting took place very quickly, even with a weak welding current, so that the depth of the weld was very small with the use of either the positive or negative pole. This too-rapid melting can be avoided by the covering. The protecting substance must melt easily and spread quickly over the surface, since the hardening occurs quickly. Thus, inclusions of the protecting material are avoided. Such inclusions must be avoided, because they would unfavorably affect the physical properties and the resistivity to corrosion.

In other countries (than Germany) the method has been employed of providing ordinary soft-steel electrodes with a protecting coat containing Cr and Ni. These elements are then expected to combine with the molten steel in the welding bath so uniformly as to form a homogeneous rustproof weld. The analysis of such welds showed great variations in their composition. The degree of rustproofness differed, owing to the uneven distribution of the alloys in the weld and also to the inclusions of slag. The physical properties also varied correspondingly.

As shown by Figure 2, the heat expansion of chrome and chrome-nickel steels differ from that of ordinary soft steel. The expansion coefficient of the chrome steels is less than that of soft steel, while that of the chrome-nickel steels is greater.

In addition to the small expansion coefficient, there is the disadvantage of volumetric change through the hardening in the welding of chrome steels. The differences on the expansion coefficients, as likewise the volumetric change due to hardening, produce in the welding a greater shrinkage in comparison with soft steel. Due to the longer welding time and also to the larger heated area in gas welding, the shrinkage is greater than in arc welding.

The greatest difficulties in welding rustproof chrome steels arise from the hardening during the welding. This hardening is shown in Figure 3. The chrome steels show an increasing hardness, with the maximum in the zone between the welded material and the added material. The chrome-nickel steels show a hardening near the weld. As a result of the loss in carbon, the weld shows a lessening in the hardness as compared with the welded material. Figure 4 shows that the hardening in the arc welds is not so extensive as in the gas welds.

The hardening of the austenitic chrome-nickel steels occurs even when the metal sheets are heated to 1200°C and quenched in oil before welding. In order to prevent hardening in the welding of chrome steels, it is necessary to heat the welded pieces to 750-850°C for half an hour and then let them cool slowly. Figure 5 shows that the hardness can be removed by a suitable thermal treatment.

The carbon-rich chrome steels attain their maximum resistivity to rust and corrosion through hardening. The carbon-poor chrome steels have the greatest resistivity in the untreated or annealed state. The austenitic chrome-nickel steels are heated to 1100-1200°C and quenched in oil and have, in this condition, the best strength characteristics and rust resistivity. These thermal treatments remove the hardness produced by welding. The weld always exhibits a less degree of hardness than the parts welded, due to the loss of carbon.

In order to determine the physical properties of welds, sheets of 4-5 mm thickness were welded. The results are given in Table IV.

TABLE IV.

Designation	Treatment	Breaking strength kg/mm²	Elongation %	Shrinkage %	Angle of blend
1	Elec. 750° ½ hr., oil	54.0	9.8	54.0	90°
1	Gas 750° ½ " "	59.8	12.0	56.2	90°
2	Elec. 750° ½ " "	51.0	11.0	-	125°
2	Gas 750° ½ " "	50.9	9.8	56.5	132°
3	Elec. 1200° ½ " "	79.2	31.7	48.6	160°
3	" 750° ½ " "	71.0	12.0	-	42°
3	Gas 1200° ½ " "	58.6	11.4	-	172°

The strength of the materials welded was attained both in the gas welding with acetylene and oxygen and in arc welding with a direct current and unprotected welding rods. The loss in the shock strength of a notched bar is slight and is ascribable to the impairment of the grain in the weld. The loss in shock strength can be prevented by forging the weld at the right temperature.

Figures 6-11 show the grain of the chrome steel, working material, transition from working material to weld and the grain of the weld. No slag inclusions nor oxides were found in the arc welds. Figure 12 shows that the difference in grain is eliminated by thermal treatment after welding. Figure 13 shows the grain of the chrome-nickel steels. Figure 14 shows the transition from the working material to the weld.

In the etchings with "Villela" (aqua regia in glycerol), it was found that the welds of chrome steels exhibited a greater resistivity than the rest of the material, the transition region being least affected (Figs. 15-16).* "Villela" will not etch gas or arc welds of chrome-nickel steel, its high resistivity being traceable to the loss in carbon, silicon and manganese. If the raised part or ridge of a chrome-steel weld is not removed, it cannot be guaranteed to be rustproof, because its surface contains inclusions.

The application of rustproof steel to ordinary steel is possible both in acetylene-oxygen and in arc welding. Figure 17 shows the transition between ordinary steel and the welding material, while Figure 18 shows the grain of the weld ridge. In order to render the applied layer rustproof, it is necessary to make two applications, because the first layers of the rustproof welding material form alloys with the soft steel underneath, so that only the second application yields a rustproof surface. The strength of the union of ordinary steel and rustproof steel is small.

The specimens of rustproof steel 1 to 4 in Table I can be firmly united by resistance welding. It is also possible to prevent the hardening by immediate annealing, i.e., by uniform heating and cooling. The rustproofness and the physical characteristics of the resistance weld depend on the properties of the welding material.

*J. V. Villela, "Delving into Metal Structures," Iron Age, Vol. 117 (1926), p. 761.

Summary

1. Rustproof steels can be easily welded by the acetylene-oxygen process.

2. The welding rods must be protected in arc welding.

3. The hardness resulting from the welding process must be removed by thermal treatment.

4. The physical characteristics of rustproof-steel welds are better than those of soft-steel welds.

5. Owing to its loss in carbon, silicon and manganese, the steel melted in the gas flame or electric arc is more rustproof after than before welding.

Bibliography

Daeves, Stahl und Eisen, 1924, No. 24.

Strauss and Maurer, Kruppsches Monatsheft, Aug., 1920.

Rappatz, "Die Edelstähle," 1925, published by Julius Springer.

"Rustproof Steel," Iron Coal Tr. Rev., Oct. 28, 1921.

Aitchison, Leslie "Chrome Irons and Chrome Steels," Engineering, Dec. 2, 1921, p.771.

Hoffmann, Diskussionsbericht No. 12 der Techn. Hochschule, Zurich, June, 1926.

Translation by Dwight M. Miner,
National Advisory Committee
for Aeronautics.

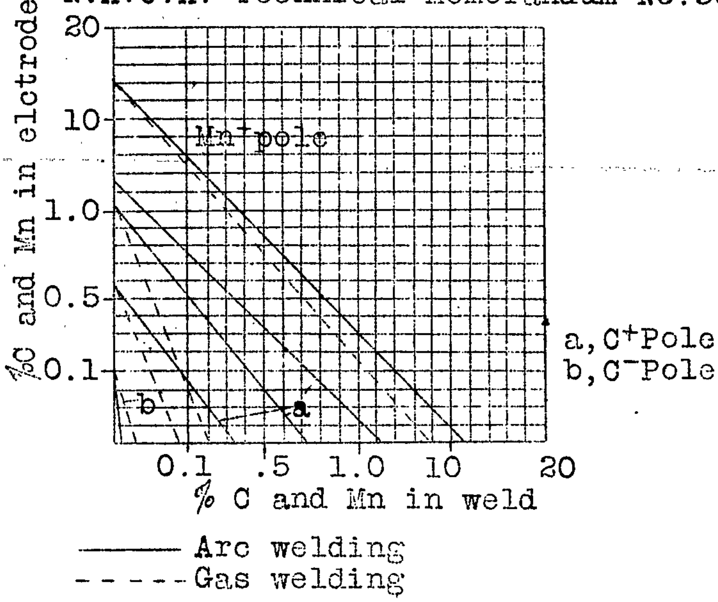

Fig.1

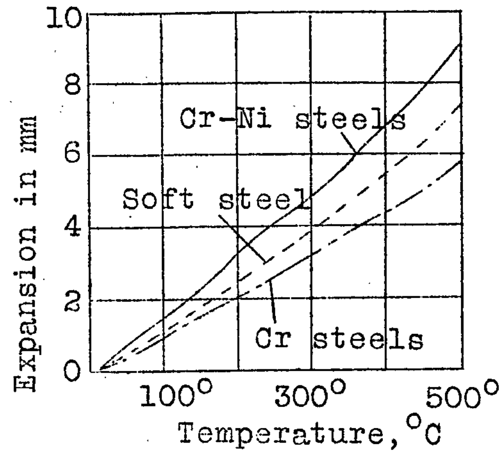

Fig.2

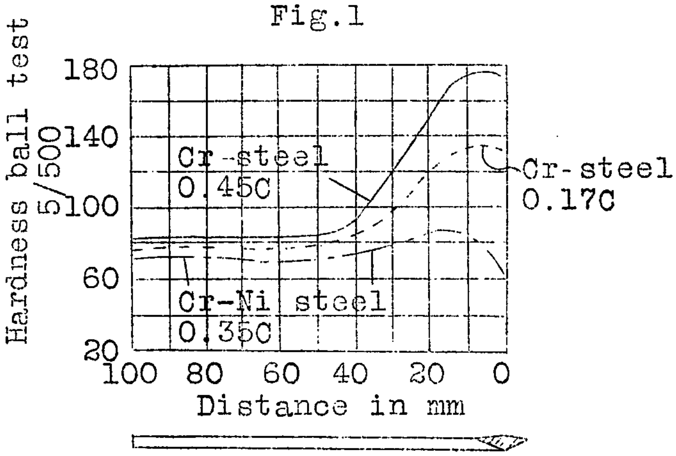

Fig.3

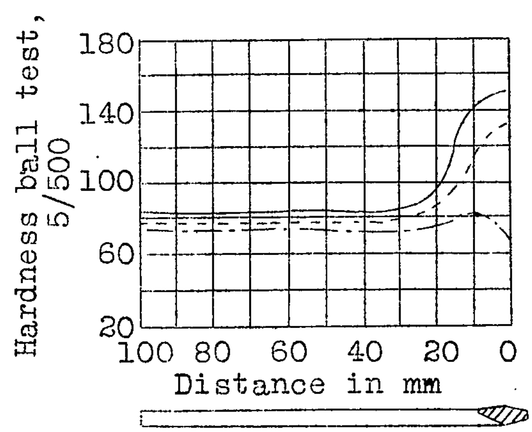

Fig.4

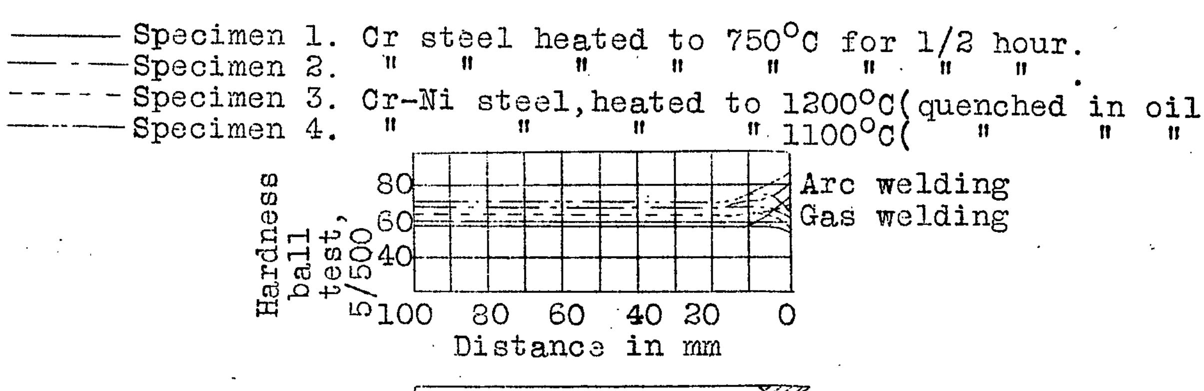

Fig.5

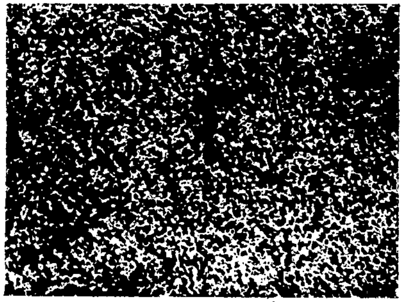
Fig.6 Etched with "Villela" C,0.45 V = 500

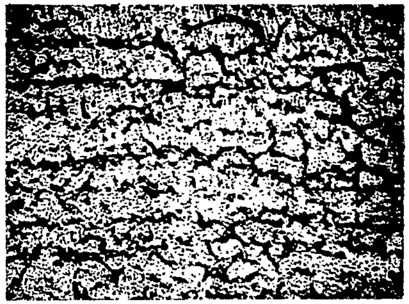
Fig.9 Etched with "Villela" C,0.17 V = 500

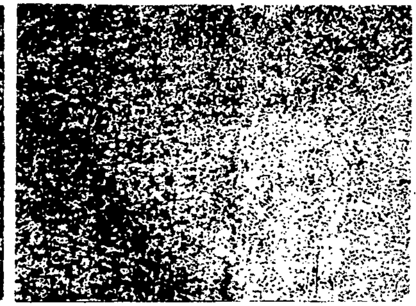
Fig.12 Etched with "Villela" C,0.08 V = 100


Fig.15


Fig.16

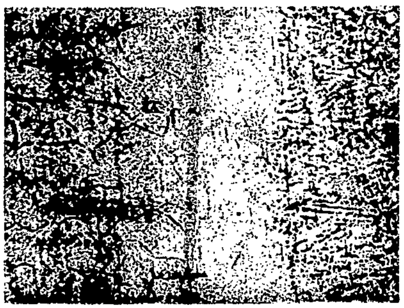
Fig.7 Etched with "Villela" C,0.38 V = 100

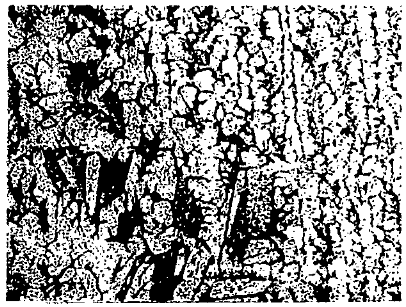
Fig.10 Etched with "Villela" C,0.08 V = 100

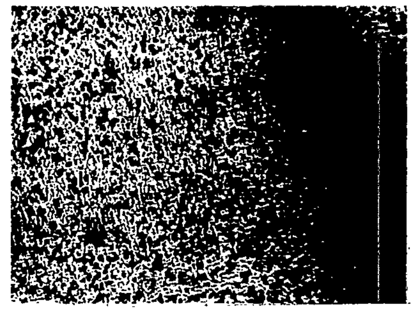
Fig.13 Etched with "Villela" C,0.35 V = 500


Fig.17 Rustproof steel. Soft steel.

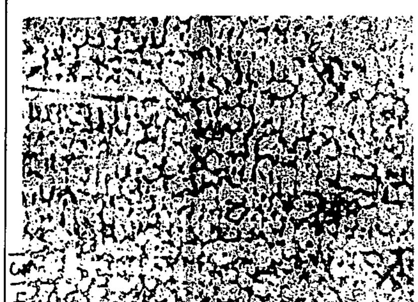
Fig.8 Etched with "Villela" C,0.18 V = 100

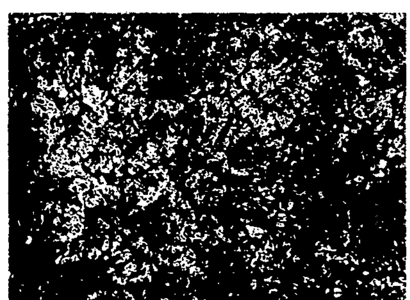
Fig.11 Etched with "Villela" C,0.05 V = 100


Fig.14 Welding material. Weld,0.08 C,0.35

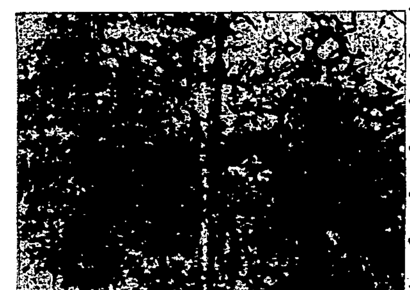
Fig.18 Etched with "Villela" V=100